Cross-shore exchanges imposed by an upwelling filament

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Upwelling filaments are mesoscale structures of cold water that stretch seaward in a tongue-like shape with origin in the coastal upwelling zone. They are upper layer features, rarely going down the top 150 m, and can reach up to 250 km long and 20 -70 km wide. Filaments represent preferred pathways for the exchange of water and dissolved and particulate matter from the productive shelf region towards the oligotrophic offshore regions. They export much more mass offshore than expected by the wind-driven Ekman mechanism. As a general rule, filaments are associated with prominent capes, but there are exceptions. Upwelling filaments are a common feature of the western margin of the Iberian Peninsula, which constitutes the northern segment of the Canary Current Upwelling System. The culminating point of SW Iberia, the Cape São Vicente, is the root of a recurrent well developed filament observed in the satellite imagery during the upwelling season, roughly defined to extend in the region from April to October.

The Cape São Vicente filament was intensively investigated through remote sensing and *in situ* multidisciplinary observations, carried out during a research cruise on board the R/V D.Carlos I, from the Portuguese Navy/Instituto Hidrográfico. The experiment took place from 22 to 25 October 2004, late in the upwelling season, during an upwelling favourable wind relaxation event, but just after a relatively intense upwelling period. The upwelling signal was still present and the associated filament, although not fully developed, was evident in the satellite sea surface temperature field (Fig. 1). A total of 42 Rosette+CTD casts up to 400 m depth were distributed on an almost regular grid of 15 km mean spacing, with reduced spacing close to the fronts. Ten standard levels were selected for water collection. The sampling was guided by satellite SST imagery transmitted to the ship in near-real time. The parameters sampled during the sea campaign comprised temperature, salinity, chlorophyll *a* (Chl *a*), dissolved oxygen, nutrients (nitrates, phosphates and silicates) and metals (cadmium, lead and zinc), along with the velocity field sampled along the ship track through a hull-mounted 38 kHz RDI ADCP and on board meteorological variables.

Seaward velocities in the filament were surface intensified, reaching over 0.8 m s^{-1} in the filament core. The filament transported 0.9 Sv of coastal water offshore, which is equivalent to the Ekman transport induced by a wind of 8.5 m s^{-1} blowing over the entire western Iberian coast (800 km). Only 8% of the filament transport is explained by the local Ekman mechanism, suggesting that the filament resulted from an alongshore equatorward upwelling jet destabilized and meandering close to the Cape São Vicente. Meanders of the jet caused vertical velocities of ±15 m/day, which had an impact upon the patchy distribution of chlorophyll-a. A shallow return flow transporting 0.4 Sv was observed in the southern flank.

Although this filament may be considered small in comparison with others in areas where upwelling is recurrent, the total amount of Chl *a* present in the filament was estimated as 180 tons, intensified as expected in the upper layers. Cross-shore transport of Chl *a* was estimated as 18 tons/day in the root of the filament, where Chl *a* concentration was higher. So, we can suppose that it takes about 10 days to be formed, a reasonable period when compared with other filaments. In a section crossing the filament further offshore the transport decayed to 8.5 tons/day. The fluxes of the three nutrients (nitrate, phosphate, and silicate) were weak in the top layers due to their consumption by the growing phytoplankton. The offshore fluxes increased with depth despite the velocity decrease, which is compensated by the higher nutrient concentration in depth. The estimated seaward nutrient transports ranged from about 1750 to 3550 tons/day for nitrates, 330 to 540 tons/day for phosphates and 2800 to 4000 tons/day for silicates, depending of the filament cross section. It must be pointed out that the transport of nutrients corresponds to a residual after consumption by phytoplankton, particularly during the period of wind relaxation that characterized the sampling experiment. Our observations show a high increase of the export of metals inside the filament core relatively to the surrounding waters, particularly offshore. The estimated offshore transports range from 18 to 26 tons/day of zinc, 17 to 31 kg/day of cadmium and 83 to 282 kg/day of lead, depending of the filament cross section.

The survey sampled the Cape São Vicente filament just after an upwelling event, but under relaxed winds. In consequence, the filament was not in it most developed stage. Considering the periods of strong upwelling events and the extent of their duration along the year, the amounts of exported matter must be hugely increased and responsible for the high productivity of the waters, showing the vital importance of the upwelling filaments to understand the functioning of the regional ecosystem.

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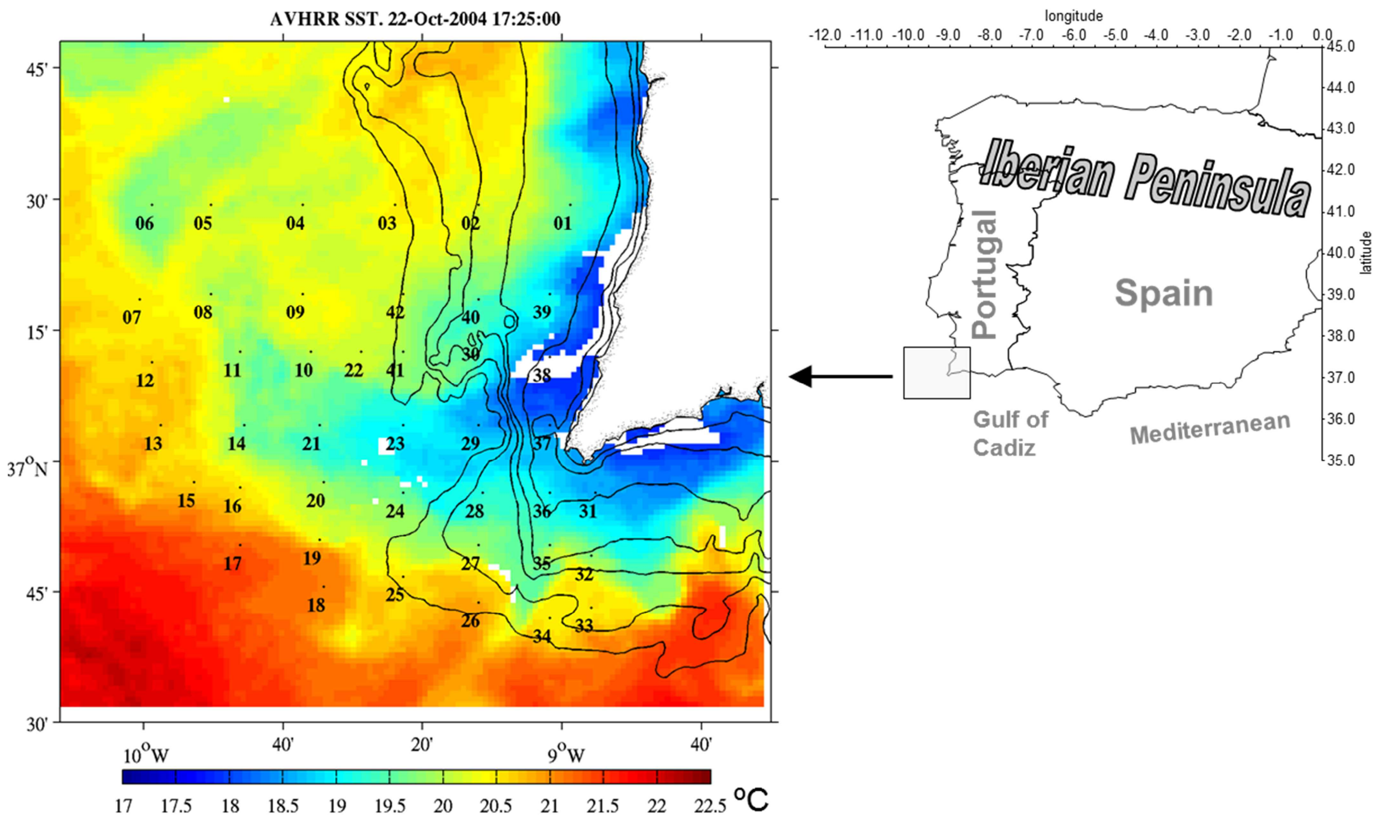

Fig. 1 - SST satellite image from 22 October 2004 showing the upwelling filament. Sampling stations and bathymetric contours are overlaid. A sketch shows the location of the sampling area.